Direct Photon-Hadron Correlations Measured with PHENIX

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Abstract.
Direct photon tagged jets are an excellent probe of the quark gluon plasma. The momentum of the photon balances the initial momentum of the opposing parton and since photons do not interact via the strong force, they escape the medium unmodified. By studying the yield opposite the photon in direct photon-hadron correlations, we measure the quark fragmentation function in $p+p$ collisions and quantify the effective modification of the fragmentation function in Au+Au collisions due to energy loss and medium response. Direct photon-hadron correlations have been measured with the PHENIX detector in $p+p$ and Au+Au collisions at $\sqrt{s_{NN}} = 200GeV$ at RHIC. A statistical subtraction to remove the large contribution of decay photons from the inclusive photon sample is employed in the Au+Au measurement. For $p+p$ collisions event by event techniques are also applied. The latest results which extend to lower z_T are compared to energy loss models.

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Direct photon-hadron correlations are considered a golden channel for studying energy loss and jet tomography in the quark gluon plasma. Since photons do not interact via the strong force, they escape the medium unmodified. Therefore the energy of the photon can be used to tag the energy of the opposing jet. Knowledge of the jet energy is necessary for measuring the fragmentation function, D(z), where $z = p_h/p_{jet}$. By measuring the awayside yield in direct photon-hadron correlations, one can measure the fragmentation function as a function of $z_T = p_T^h/p_T^\gamma \approx z$.

The $\gamma - h$ correlations are constructed by measuring the azimuthal angle, $\Delta\phi$, between the trigger photon and the charged hadrons in the event. The correction for detector acceptance effects in the shape of the $\Delta\phi$ distribution is estimated by mixing the trigger particles with associated hadrons from other events. In heavy ion collisions, the large combinatorial background resulting from the high multiplicity of the event needs to be removed. This background level, b_0, is determined using the absolute normalization method [1]. This background must also be modulated by the flow which produces an angular correlation between particles. In this study only the elliptic flow, v_2, is included in the subtraction. It is assumed that the contributions from higher order flow terms would be negligible for high momentum triggers in the most central collisions. The subtraction is performed according to Eqn. 1. The charged hadron efficiency, ε^a, is determined via a full GEANT simulation of the detector.

$$\frac{1}{N^t}\frac{dN^{pair}}{d\Delta\phi} = \frac{1}{N^t}\frac{N^{pair}_{real}}{2\pi\varepsilon^a}\left[\frac{dN^{pair}_{real}/d\Delta\phi}{dN^{pair}_{mix}/d\Delta\phi} - b_0\left(1+2\langle v_2^t v_2^a\rangle\cos\left(2\Delta\phi\right)\right)\right]. \tag{1}$$

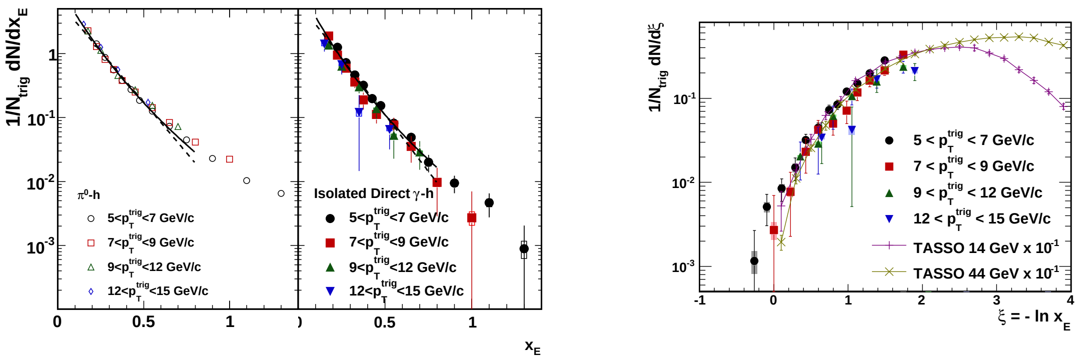

FIGURE 1. (Left) Direct photon-hadron yield as a function of x_E for the isolated direct photon-hadron $p+p$ measurement. (Right) $p+p$ yields vs. ξ compared to TASSO data scaled down by a factor of 10.

The jet function is measured for inclusive photons, i.e. all photons in event. However, most of these photons are actually from meson decays. To extract the direct photon-hadron signal, the contribution to the correlations from the decay photons must be removed. To do this, $\pi^0 - h$ correlations are measured and mapped to decay photon-hadron correlations according to the probability for a π^0 to decay into a photon within a particular p_T bin as determined from a Monte Carlo study.

With the yields from the $\gamma_{inc} - h$ and $\gamma_{dec} - h$ correlations in hand, the $\gamma_{direct} - h$ correlations are extracted from the inclusive correlations according to Eqn. 2

$$Y_{\text{dir}} = \frac{R_\gamma Y_{\text{inc}} - Y_{\text{dec}}}{R_\gamma - 1}. \qquad (2)$$

where Y are the per trigger yields for the various correlations and R_γ is the ratio of the number of inclusive photons to the number of decay photons which has been measured previously [2].

In $p+p$ collisions, decay photons are also removed on an event by event basis. By improving the signal to background ratio prior to performing the previously described subtraction, the uncertainties in the measurement are reduced. First an isolation cut is applied which requires the total momentum and energy within a 0.3 rad cone around the trigger photon to be $< 10\% E_\gamma$. In addition to removing the decay photons, this also reduces the fragmentation photon contribution. Second, photons are excluded which, when paired with another photon in the event, fall within the π^0 or η mass windows [3].

Because of the high multiplicity background, it is difficult to apply these techniques in Au+Au collisions. Therefore only the statistical subtraction procedure was used in the Au+Au analysis. However, in the $p+p$ analysis the event by event techniques improve the uncertainty relative to the analysis without them while the results remain consistent.

The yield on the awayside, $|\Delta\phi - \pi| < \pi/2$, of direct photon-hadron correlations in $p+p$ collisions is plotted as a function of x_E in Fig. 1, where $x_E = \frac{p_T^h \cos\Delta\phi}{p_T^\gamma} \approx z$. All the data points appear to lie on a universal curve. A simple exponential fit, $\frac{dN}{dz_T} = Ne^{-bz_T}$, to all points gives a slope of b=8.2 $\pm$ 0.3 which is consistent with the expectation of b=8 for quark jets as opposed to b=11 for gluon jets [5]. At Leading Order, direct photons are predominantly produced when a quark and gluon scatter and produce a photon and opposing quark jet. Therefore, direct photon-hadron correlations measure the quark fragmentation function.

An alternative way to plot the fragmentation function uses $\xi = -ln(x_E)$. The $p+p$ data is plotted as a function of ξ in Fig. 1 and agrees well with the quark fragmentation function as measured by TASSO in e^+e^- collisions. The arbitrary scale factor on the TASSO points corrects for the swing of the awayside jet in η which is not corrected for in the PHENIX measurements. Since x_E scaling holds for triggers in the range, $5 < p_T < 15$ GeV/c, the distributions for the different trigger bins have been combined. The blue points in Fig 2 are the combined $p+p$ results from Fig. 1. Again, the $p+p$ distribution agrees well with the TASSO data for the quark fragmentation function drawn as green triangles with a connecting line.

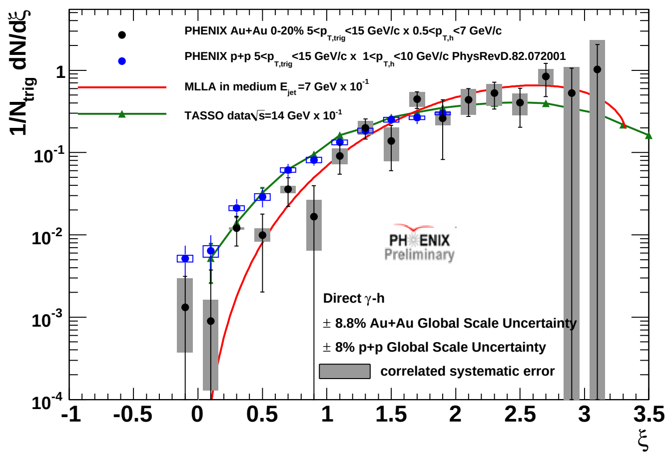

FIGURE 2. ξ distribution for PHENIX Au+Au data (black circles) and $p+p$ data (blue circles) compared to the scaled TASSO data (green triangles) and MLLA in medium prediction (red line).

The ξ distribution for the Au+Au from the 2007 RHIC Run is shown in Fig. 2 as black points. The points at low ξ exhibit suppression compared to the blue $p+p$ data points. Moving toward higher ξ the suppression diminishes. This behavior is more clearly illustrated by the I_{AA} plotted in Fig. 3. The $I_{AA} = Y^{pp}/Y^{AA}$ which is the ratio of the yields from Au+Au to that in $p+p$. The I_{AA} stops at $\xi = 1.8$ because the $p+p$ measurement was limited to hadrons with $p_T > 1$ GeV/c. However, to study the behavior at higher ξ the Au+Au data included hadrons with p_T as low as 0.5 GeV/c. Since the $p+p$ distribution agrees well with the TASSO data in the overlapping region, the TASSO distribution is used as a baseline for the higher ξ Au+Au points. The ratio of the Au+Au and the TASSO data for similar jet energies is shown in the right panel of Fig. 3. The suppression seen at low ξ agrees with the linear fit to the I_{AA}. The points at higher ξ appear to deviate from this flat line which indicates a shape change between the two measured fragmentation functions. This rise at the highest ξ also suggests an enhancement but, with the current uncertainties, is only a little more than a one sigma effect. It is important to note that one should interpret this ratio with caution, since k_T and other initial state effects, which are not present in e^+e^- collisions, could alter this distribution.

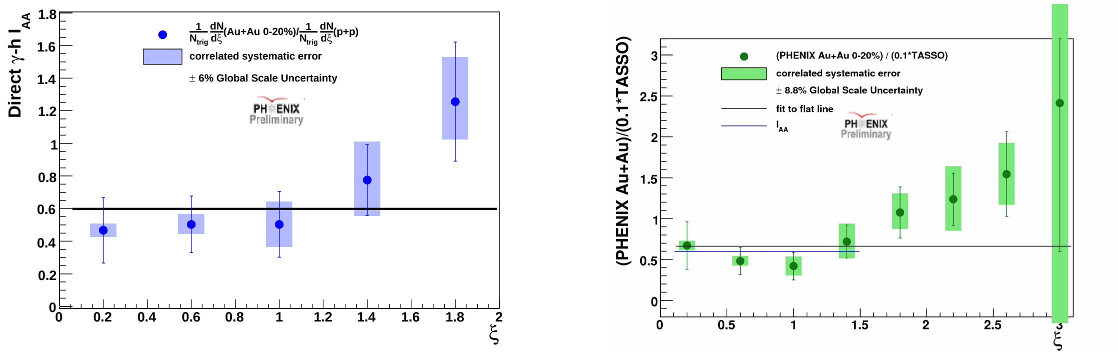

FIGURE 3. (Left) Direct photon-hadron I_{AA} using isolated $p+p$ measurement as the baseline for the Au+Au. (Right) Ratio of Au+Au data to TASSO data scaled by a factor of 10. The black line is a fit to this ratio while the blue line is the fit to the I_{AA}.

The red curve in Fig. 2 is based on a model [6] that uses the Modified Leading Logarithm Approximation and assumes that the energy that partons loose in the medium goes into soft particle production. Therefore, according to the model, one would expect to observe an enhancement at high ξ. Although the possible enhancement observed in the data is statistically limited, the model curve describes the data well with $\chi^2/NDF = 0.84$ supporting the idea that the energy lost at low ξ is redistributed to high ξ particles.

In conclusion, the fragmentation function has been measured in $p+p$ and Au+Au collisions using direct photon-hadron correlations at PHENIX. Improved event by event techniques reduce the uncertainty in the $p+p$ baseline for the Au+Au measurement. The $p+p$ fragmentation function is consistent with quark fragmentation expectations. Suppression has been observed in Au+Au compared to $p+p$ which results in an average $I_{AA} = 0.6 \pm 0.1$. Although the points at low ξ exhibit constant suppression, a rise in I_{AA} may be observed toward higher ξ. To investigate this beyond the current $p+p$ analysis, the ratio between the Au+Au and e^+e^- collisions from TASSO is also measured and indicates that the shape of the measured fragmentation functions is different for the two collision systems and suggests a possible enhancement at the highest ξ values. However, this warrants further studies and an extension of the $p+p$ analysis. Additional data collected in the 2010 and 2011 Au+Au runs will also improve the statistical precision of this measurement.

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